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Geotechnical Approaches for Slope Stabilization in Residential Area

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Abstract

Slopes in soils and rocks are found in nature and in-made structures. Highways, dams, levees, canals and stockpiles are constructed by sloping the lateral faces of the soil because slopes are generally less expensive than constructing the wall. Natural forces such as wind and water change the topography on Earth and other planets, often creating unstable slopes. In Malaysia, the number of slope failures includes existing slopes and newly completed slopes that caused damage and inconvenience to the public. Recently the landslide failures in Hulu Langat (2011) and Bukit Antarabangsa (2008) have been given due notice by the government to mitigate serious occurrence. As we live in tropic region and most landslides that occur during two monsoon seasons of Malaysia are induced by the high rainfalls and more than 80% of landslides are caused by man-made factors, mainly design and construction errors. [1]. Whether it is slope in the design stage or an actual existing real slope which has shown instability, there are some causes of the instability which are indicated in the analysis or which have developed in practice. Many types of remedial and corrective measures for slope stabilization have been used in practice such as cut and fill solutions, rock and soil anchors, drainage, several types of drains (shallow, deep and trench), retaining wall and the use of geo grids in embankments. This study concerns the stability of natural man-made slopes and focus more to new and existing remedial techniques of slope protection. For this research the limitation of studies are observations on existing and new slopes remedial works in residential area at Perak District, Malaysia.

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1. Introduction

Landslides, slips, slumps, mudflows, rock falls – these are just some of the terms which are used to describe movements of soils and rocks under the influence of gravity. These movements can at best be merely inconvenient, but from time to time they become seriously damaging or even disastrous in their proportions and effects. We are normally more aware of hazards arising from the earth's surface processes in terms of flooding and short-term climatic effects, but in other parts of the world, slope instability too, is widely recognized as an ever-present danger. Landslides and other gravity-stimulated mass movement are important and costly problems, and they are a continual source of concern for geotechnical engineers and engineering geologists throughout the world, particularly in geologically 'active' regions.

Slopes in soils and rocks are found in nature and in man-made structures. Highways, dams, levees, canals and stockpiles are constructed by sloping the lateral faces of the soil because slopes are generally less expensive than constructing a wall. Natural forces such as wind and water change the topography on Earth and other planets, often creating unstable slopes. Geotechnical engineers have to pay particular attention to geology, surface drainage, groundwater, and the shear strength of soils in assessing slope stability. The analyses of slope stability are based on simplifying assumptions and the design of a stable slope relies heavily on experience and careful site investigation.

Slope failures depend on the soil type, soil stratification, groundwater, seepage and slope geometry. A common type of failure is homogeneous fine-grained soils, a rotational slide that has its point of rotation on an imaginary axis parallel to the slope.

As we can see on highways and road constructions, a flow slide occurs when internal and external conditions force soil to behave like a viscous fluid and flow to even shallow slopes, spreading out in several directions. Flow slides can occur in dry and wet soils. Slope failures are caused, in general, by natural forces, human misjudgement and activities of burrowing animals.

Traditionally, engineers use concrete, rock wall or framework to fix the excavated slopes and road embankments, but the cost is high and at the same time leads to further environmental problem because passengers do not want to see white concrete during travelling, instead of green vegetation. Following economic development people pay more attention to the quality of environment. As a result, highway engineers started to use bio-engineering method to protect the roads and the slopes along the roads.

2. Objective

This research has the main objectives of understanding the stability of natural and man-made slopes and therefore could aims to define types of slopes and various categories of slope failures. The objectives of the study are to define the configuration of slopes and various categories of slope failures, to study existing and new remedial techniques and also method and design elements for slope protection at new residential area. First, studies of typical slope failures were carried out by visiting and inspecting the sites. Field survey includes pictures of the site, configuration of slope surfaces, failures and the geometry of slopes. Then, graphical and data analysis were done to classify slopes and failure cases. Many new remedial techniques were seen at the site and identified as the most widely used at residential areas. This study indicates that most cut slopes, even with mild sloping, still fail after a long period of time. There are many remedial methods used to stabilize slopes at residential areas. Based on our observations, we found that most of the soil condition at Perak District use simple remedial works to retain the slopes without

using other additional methods. A particular area, which is Gerik, Perak, has been identified as a high-risk landslide activity. The remedial works used many retaining structures to stabilize the slopes.

3. Literature Review

The literature review study is a primer process carried out initially to start a study. It proposes to give an early overview on any information related to the study that will be done later. The understanding of certain matters such as the theory and basic subtopics will narrow down to the actual topic that is being studied. In the study of slopes, the slope construction basic theory is very important in regards to types of soil, soil movement and stabilizing methods. Slope construction is closely related to soil and it is crucial that we understand the background of soil and slope analysis methods that have been practiced in the construction of new slopes or remedial of existing slope.

In every slope there are forces which tend to promote down slope movement and opposing forces which tend to resist movement. A general definition of the factor of safety, F , of a slope results from comparing the down slope shear stress with the shear strength of the soil, along an assumed or known rupture surface. Starting from this general definition, Terzaghi [2] divided landslide causes into external causes which result in an increase of the shearing stress (e.g. geometrical changes, unloading the slope toe, loading the slope crest, shocks and vibrations, drawdown, changes in water regime) and internal causes which result in a decrease of the shearing resistance (e.g. progressive failure, weathering, seepage erosion).

However, Varnes [3] pointed out a number of external or internal causes which may be operating either to reduce the shearing resistance or to increase the shearing stress. There are also causes affecting simultaneously both terms of the factor of safety ratio. A great variety of slope movements reflect the diversity of conditions that cause the slope to become unstable and the processes that trigger the movement. It is more appropriate to discuss causal factors (including both “conditions” and “processes”) than “causes” per se. Thus ground conditions (weak strength, sensitive fabric, degree of weathering and fracturing) are influential criteria but are not causes. They are part of the conditions necessary for an unstable slope to develop, to which must be added the environmental criteria of stress, pore water pressure and temperature. It does not matter if the ground is weak as such failure will only occur as a result if there is an effective causal process which acts as well. Such causal processes may be natural or anthropogenic, but effectively change the static ground conditions sufficiently to cause the slope system to fail, i.e. to adversely change the stability state Popescu, [4]. Seasonal rainfall and evaporation is reflected in seasonal variations in the factor of safety. Should there be a long-term trend in groundwater levels, or changes in strength due to weathering, these will show as a trend imposed on the seasonal variation. Sudden changes will be due to short-term variation in either the strength of the materials or the forces applied to the slope.

3.1 Factors that Provoke Slope Failure

3.1.1 Erosion

Water and wind continuously erode natural and man-made slopes. Erosion changes the geometry of the slope, ultimately resulting in slope failure or more aptly, a landslide, river and streams continuously scour their banks undermining their natural or man-made slopes.

3.1.2 Rainfall

Long periods of rainfall saturate, soften and erode soils. Water enters into existing cracks and may weaken underlying soil layers, leading to failure, e.g. mud slides.

3.1.3 Earthquakes

Earthquakes induce dynamic forces especially dynamic shear forces that reduce the shear strength and stiffness of the soil. Pore water pressures in saturated coarse-grained soils could rise to a value equal to the total mean stress and cause these soils to behave like viscous fluids, a phenomenon known as dynamic liquefaction. Structures founded on these soils would collapse, structures buried within them would arise. The quickness (a few seconds) in which the dynamic forces are induced prevents even coarse-grained soils from draining the excess pore water pressures. Thus, seismic failure even often occurs under undrained conditions.

3.1.4 Geological Features

Many failures commonly result from unidentified geological features. A thin seam of silt (a few millimetres thick) under a thick deposit of clay can easily be overlooked in drilling operations or one may be careless in assessing borehole logs only to find later that the presence of the silt caused a catastrophic failure. Sloping, stratified soils are prone to translational slide along weak layers (s).

3.1.5 External Loading

Loads placed on the crest of a slope (the top of the slope) add to the gravitational load and may cause slope failure. A load placed at the toe, called a berm, will increase the stability of the slope. Berms are often used to remediate problematic slopes.

3.1.6 Construction Activities

Construction activities near the toe of an existing slope can cause failure because lateral resistance is removed. We can conveniently divide slope failures due to construction activities into two cases. The first case is excavated slopes and second case is fill slopes.

When excavation occurs, the total stress is reduced and negative pore water pressure is generated in the soil. With time the negative pore water pressure dissipates, causing a decrease in effective stress and consequently lowering the shear strength of soil. If slope failure is to occur, they would take place after construction is completed.

Fills slopes are common in embankment construction. Fill (soil) is placed at the site and compacted to specifications, usually greater than 95% Proctor minimum dry unit weight. The soil is invariably unsaturated and negative pore water pressure develops. The soil on which the fill is placed, which is called the foundation soil, may or may not be saturated. If the foundation soil is saturated, then positive pore water pressure will be generated from the weight of the fill and the compaction process. The effective stress decreases and consequently the shear strength decreases. With time the positive pore water pressure dissipates, the effective stress increases and so does the shear strength of the soil. Thus, slope failures in fill slopes are likely to occur during or immediately after construction.

3.1.7 Rapid Drawdown

Reservoir can be subjected to rapid drawdown. In this case the lateral force provided by the water is removed and the excess pore water pressure does not have enough time to dissipate. The net effect is that the slope can fail under undrained conditions, seepage of groundwater would occur and additional seepage forces can provoke failure.

4. Methodology

It is very important to understand the configuration and scale of slope as well as dynamic condition, in an investigation of actual condition of a slope and design of countermeasures. Even in whole structure of slope, rational investigation and countermeasures that can be programmed in early stage of slope cannot be identified, and general tendency of slopes can be recognized by estimating one of the configuration properties, namely slope width, length, and depth.

For this purpose, it is necessary to clarify the relationship between each property from analysis of features of existing slopes. From this point of view, the relationship between scale of slopes and configuration or slope angle based on examples that were taken from sites in which actual conditions such as sliding extent or depth were known.

4.1 Configuration and Scale of Slopes

The configuration properties of slopes can be defined as follows:

Width of slopes (W): maximum width of slopes

Depth of slopes (D) : maximum depth of slide plane in vertical direction

Length of slopes (L): distance between the head and toe of landslide

Slope angle (β) : inclination of line between the head and toe of slope to a horizontal direction.

Figure 1 and 2 show how configuration properties is determined

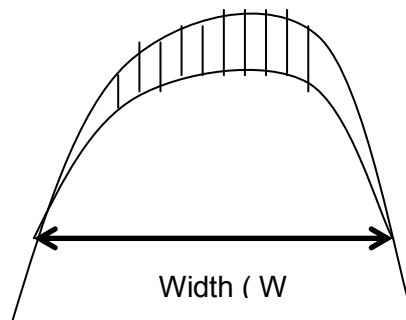


Fig 1 Figure shows how slope width is determined

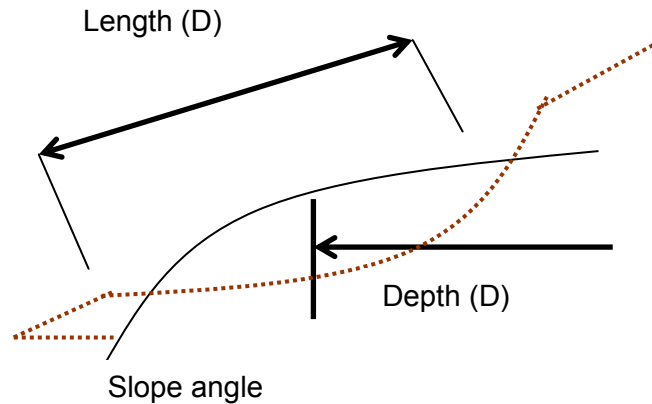


Fig 2 Figure shows how length, depth of slopes and slope angle are determined

5. Finding

There are many methods in stabilizing the slopes in residential areas. Based on observations that have been made at a few districts in Perak, some methods have been identified that, in line with what Broms and Wong [5], said in general. There are three main groups of remedial measures;

1) Geometrical Method

This is the most common method that has been used in residential areas in Perak. This method is usually simple and less costly as shown in Figure 3. The changing of the slope angle from steep slope to a gentler slope may increase the stabilization of slope and the angle is usually supported by grass bonding together with soil. Residential areas were built on a wide area to facilitate construction of remedial work. This conventional method of angle grading requires some excavation. This type of method does not require heavy load resistance and naturally stabilize the slope with the creepy grass surface. This method is the most widely used in the residential areas in Perak, which requires minimum maintenance. Some areas combine this method with retaining the building structure at the toe of slope in the Kinta district as shown in Figure 4. This method, however, may also be similar to the Geometrical, Surface Drainage and Retaining Structure method.



Figure 3. Geometrical Method with Grass Bonding



Figure 4. Combination of Geometrical Method with Gabion Wall at the toe of slopes

2) Drainage Method

One of the slope failure factors is saturation and pore water pressure building up in the subsoil. If drainage system had been provided, the chances of building up pore water pressure and saturation of subsoil can be minimized. This method can be very effective. However, in the figure 5 the drainage system must be maintained in order to perform effectively. It is easy to maintain the surface drains, but it is difficult to maintain the subsoil drains. Subsoil drain is mostly found in the retaining structure as weep holes method and cut off drain as shown in Figure 6. In general, this method is used in combination with other methods. Surface drain was used mostly with geometrical method while the sub soil drain is part of the method combined with the retaining structure. Surface drain is capable of discharging more water, especially during heavy rain to avoid the effects of large amounts of water absorption by the slope.



Figure 5. Surface Drainage at Tanjung Malim and Batu Gajah, Perak



Figure 6. Weep holes on slopes

3) Retaining Structures Method

This method is generally more costly. However, due to its flexibility in a constrained site, it is always the most commonly adopted method. The principle of this method is to use a retaining structure to resist the downward forces of the soil mass. The retaining structures as shown in figure 7 and 8 include gravity types of retaining wall, cantilever wall, contiguous bored piles, cassion, and steel sheet pile. Ground anchors or other tie back system may be used together with the retaining structures if the driving forces are too large to resist. This method also involves rigid slope surface protection such as shotcrete, masonry and stone pitching. Shotcrete is applying mortar on a slope surface by a certain thickness. Masonry and stone pitching may stabilize the slope to eliminate the failure at face slope. It also may reduce rainwater infiltration and prevent slope erosion of the slope forming materials. A slope will be relatively stable when its profile (section angle) is kept below its angle of repose. Angle of repose is an angle that maintains naturally to a safe equilibrium by the composing material of a slope. This angle deviates from differing materials depending on compaction, particle size and the nature of the material itself.



Figure 7. Rubble pitching and retaining wall at Lenggong, Perak



Figure 8. Rubble Pitching, Earth reinforced retaining structure and turfing of slope surface

6. Conclusion

Slope is considered stable if the shear force in the soil acts as a force retainer against gravity that caused high geostatic stress when earth surface is at certain angles. Geostatic stress consists of vertical stress and horizontal stress or known as lateral stress. Imposed load includes soil loading of structures that is right on sloping soil or loading happens at a nearby area. Soil is still free to act and reduce the bonding force between each other. If the stress is more than the soil shear force, landslide will occur. Other than that, development in upstream area will cause water that flows downstream to increase, and will contribute to land failure. The flowing water can be flowed safely with the construction of drainage system or a retention pond. The condition in Bukit Lanjan, Selangor showed the occurrence of landslide and caused the bridge at the highway to collapse because of water overflow from the construction upstream. Meanwhile the landslide of several bungalows at Bukit Antarabangsa and recently at the Orphanage Home at Hulu Langat, Selangor in April 2011, proved that slope remedial works should not be ignored and is required for successful slope stabilization.

From the methods used in this study, slope surface configurations determined by data collection have birth the idea of retaining structure design. These early steps are important to identify the cause of slope instability and failure. Apart from the soil stress factor, be it lateral or horizontal stress, the climate factor in Malaysia, which is hot and humid contributes to soil failure. Even though the failure is minor, and only involves a few slope surfaces, the long term effect will cause the soil to be exposed to the sun and rain, if the failure area is not covered by soil reinstatement. Most slopes that we see are only using blue plastic cover to cover the sliding or corrosive surface as a temporary way to stop rain water and air from going in the soil.

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